IN-ICE OPTICAL MEASUREMENTS AND THEORY

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LONG-TERM GOALS

The long-term goals of this program are; to study the relationship between the optical properties and physical characteristics of the sea ice, and to provide an inverse model to be able to derive the inherent optical properties from the apparent optical properties.

OBJECTIVES

The objective of this study is to make detailed measurements of the radiance field within sea ice along with concurrent measurements of the physical and biological characteristics of the ice. The radiance measurements are necessary for our objectives to test forward radiative transfer models and to develop inverse models.

APPROACH

In order to measure the radiance as a function of depth, zenith angle, and azimuthal angle, a series of holes are drilled into the ice. Each hole corresponds to a particular zenith and azimuthal angle combination. Once the holes are drilled we insert the spectroradiometer detector head and vertical profiles of the radiance perpendicular to the direction of the hole are measured. To ensure that the detector head is always looking towards undisturbed ice the first hole drilled is vertical and later holes are drilled at smaller angles. The spectroradiometer was developed for this project and consists of a detector head designed to fit within the hole left by a 4 inch core drill, and a separate surface unit that contains a heater and spectrometer. The two sections are connected by a fiber optic cable. The spectrometer measures 28 wavebands between 430 and 685 nm at approximately 9 nm intervals. The radiance detector head has a 3 degree acceptance angle and light shields on top and bottom to prevent detection of light propagating along the axis of the hole.

In order to understand how the light field within the ice depends on the properties within the ice we are combining the optical measurements that we collected with measurements of the physical and biological ice characteristics as well as applying the data to radiative transfer models. We are collaborating with Drs. Perovich and Roesler, so that we use the complete set of optical, physical, and biological measurements to fully characterize the ice and its related optical properties. To improve optical models of sea ice we have been collaborating with Drs. Jin and Stamnes to test their radiative transfer model and its

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associated optical property model. We are also working with Dr. Stamnes to model the asymptotic light field within the ice. The goal is to determine the conditions in which an asymptotic light field exists and the shape of the asymptotic radiance distribution. Based on the shape of the radiance distribution we will invert the radiance measured at three angles to provide the inherent optical properties.

TASKS COMPLETED

We have developed an inverse model based on the asymptotic radiance distribution to provide the inherent optical properties from the measured radiance distributions.

We have worked with Dr. Stamnes to use a radiative transfer model to provide a model of the shape of the asymptotic light field and the conditions in which we can expect to observe the asymptotic light field.

We have tested our inversion model to obtain the inherent optical properties from the radiance measurements.

In-ice radiance measurements made during the first three years of this project are available to other investigators for use in radiative transfer models.

RESULTS

Radiance measurements were made in first year ice at two locations approximately 30 m apart during the 1995 field season. The radiance and associated attenuation profiles were found to be dependent on the small-scale physical structure as well as the optical properties of inclusions in the ice (Figure 1). The light field is expected to deviate from the asymptotic state near these structural changes. There are, however, large regions that do not contain significant structural variability where the asymptotic state may be reached. In the asymptotic state the radiance attenuation coefficient is independent of angle. The radiance attenuation data shows that this is approximately true at depths of greater than 25 cm in the ice (Figure 2). Radiative transfer modeling confirmed that the light field should be nearly asymptotic by 30 cm within the ice. The existence of an asymptotic light field is important for the inversion of the radiance measurements to give the associated inherent optical properties.

Model results indicate that even though the light field is nearly asymptotic by 30 cm it takes another 30 to 40 cm before the shape of the radiance distribution becomes constant. The changes in the shape of the light field beyond 30 cm depth are small (~ 2%) and thus we can use the asymptotic theory for measurements made nearer the surface. Inherent optical properties calculated using an inversion model of the radiance distribution were within a factor of two of the modeled scattering coefficient (the model uses physical parameters to estimate the optical parameters) and the measured absorption coefficient. The inversion estimates of the single scattering albedo and Heney-Greenstein asymmetry parameter were within 2% of the values estimated by the forward optical model. We thus feel that the inversion technique provides a valuable technique for obtaining inherent optical properties using relatively simple measurements.

IMPACT/APPLICATIONS

The factors that affect the attenuation of light is important for modeling of ice melt and the subsequent questions about the role of ice in changes to the global weather system. There is very little previous data on the light field within sea ice. This data set can be used to evaluate the performance optical models of ice used in radiative transfer models and the output of the radiative transfer models themselves.

TRANSITIONS

Dr. Stamnes of the University of Alaska is using the radiance measurements to test his sea ice radiative transfer model. He anticipates using the model as a portion of his future arctic research.

The measurement equipment has been shipped to the field for use in the NSF sponsored Surface Heat Budget of the Arctic (SHEBA) project.

RELATED PROJECTS

We have been sponsored to work in the SHEBA project measuring the physical and optical parameters of the leads. We also plan on working with the sea ice group to supplement their optical measurements.

REFERENCES

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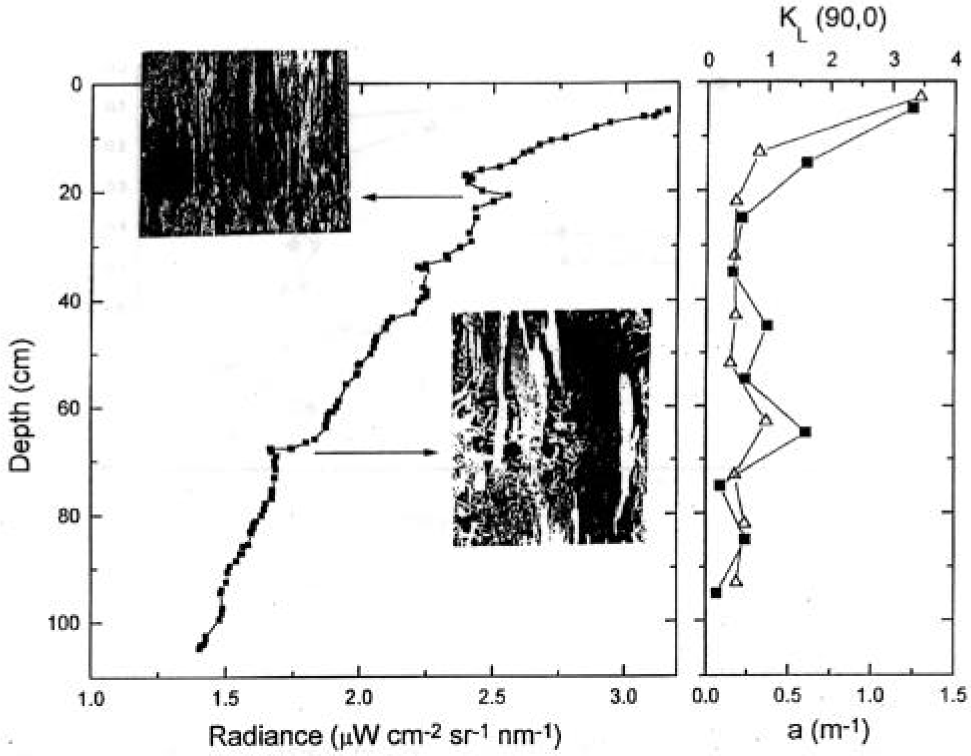

Figure 1. This figure from Perovich et al. 1997 demonstrates that irregularities in the radiance profile were correlated with small-scale structural changes. At 20 cm depth there is a boundary in the crystal growth that is seen as a local increase in the radiance at $\theta = 90°$. Near 70 cm depth a layer of irregular crystals were embedded in the ice and there was a corresponding decrease in the radiance measurement. The attenuation profile is also similar in shape to the absorption profile (K values are the solid squares).

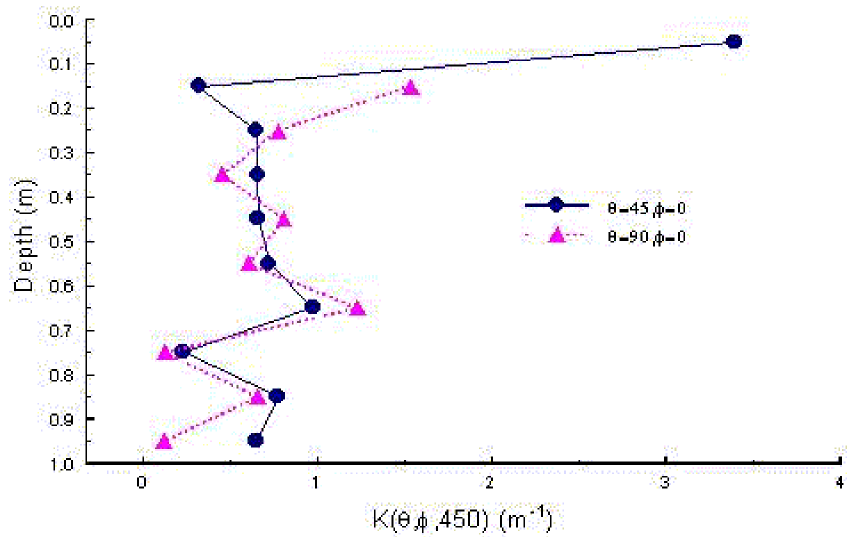

Figure 2. Attenuation profiles at two polar angles. The attenuation at both angles is nearly the same below 25 cm which suggests that the light field may be nearly asymptotic.